CHAPTER 8

CANALIZED WATERWAYS

Section I. Principal Features

8-1. Locks and Dams. Some streams can be developed for navigation only through the use of a series of locks and dams, with or without training and channel stabilization structures. Generally, locks and dams would be required in streams having steep gradients with velocities too high for navigation, of inadequate depths particularly during low-water periods, or where conditions make it impractical to develop the required depths by contracting structures because of rock outcrops, sediment movement, or the effects of such structures on velocities affecting navigation and on the flood-carrying capacity of the stream.

8-2. General Description. Lock and dam structures provided primarily for navigation usually consist of one or more locks, a dam or spillway for the maintenance of a minimum upper pool level, and other accessories as required to assist navigation and to provide for the passage of flood flows. These structures are usually of the low-lift type with lifts varying from a few feet to in excess of 30 feet. The lock or locks usually include guide and/or guard walls, an esplanade, and filling and emptying systems. The dam could be of the navigable or nonnavigable type and could include a gated or controlled spillway, overflow weirs and embankments, navigable passes, and overbank embankments.

8-3. Navigable Dams. Navigable dams have been used on some streams with low-lift locks and are provided with a controllable section such as bear traps and a navigable pass which is opened to navigation when discharges are sufficient to provide adequate depths without the effects of the dam. Navigable passes are designed to provide safe transit for all traffic expected to use the waterway when flow conditions permit. Because of the operational difficulties and the frequent inundation of the low-lift locks, these structures are considered more or less obsolete. The navigable-type dams on the Ohio River are being replaced with nonnavigable dams to provide for higher and longer pools, larger locks, and more efficient operation. Navigable dams usually have little effect on flood stages since the elements of the dam are on the channel bed during high water except for small piers and the locks are overtopped. Planning of navigable dams is discussed in EM 1110-2-2606.

8-4. Nonnavigable Dams. Practically all of the newer dams are of the nonnavigable type and are designed to maintain a constant upper pool as long as conditions will permit and to pass the higher flows with a small backwater effect. The magnitude of backwater for nonnavigable dams is determined through a cost effectiveness analysis. This analysis considers several spillway lengths and overflow weirs with the smaller lengths causing a higher upstream backwater elevation. The minimum cost layout will be the most cost effective. With nonnavigable dams the minimum number of gates should be based on operational flexibility, particularly when one or two gates are down for maintenance or repairs. The minimum number of gates should be determined project by project based on experience and engineering judgment. A higher upstream water-surface profile could increase project cost by:

a. Requiring more land acquisition or flood easements.

b. Consequential damages for increased flood heights and groundwater elevations.

c. Requiring longer, higher levees.

d. Requiring higher lock and dam.

e. Requiring more relocation.

The potential savings are reduced size of spillway, overflow weirs, stilling basin, and exit channel widths. Also, a narrower spillway exit channel will keep sediment moving in alluvial streams and reduce maintenance dredging. In some cases, locks and dams are designed for hinged pool operation that would permit the lowering of the pool level some 3 to 5 feet in anticipation of a flood upstream, provide for powerhouse releases upstream, or change the movement of sediment and location of shoal areas. To provide adequate flow capacity within the streambanks and for the passage of sediment, the crest of the sills of the spillway gates is usually at or near the elevation of the natural streambed. When the length of the spillway is less than the width of the channel between the river-side lock and the far bank, an overflow section or weir might be placed within the channel to supplement any overflow structures along the overbank.

Section II. Overflow Sections

8-5. Substitute for Gate Bays. Overflow sections or weirs can also be used as a substitute for some of the gate bays by being placed in a part of the channel cross section usually on the side opposite the lock or locks and are designed to pass with the overbank section some of the flow during higher river stages. Overflow weirs or sections are usually cheaper than the portion of the spillway and stilling basin they replace but also could reduce the maximum discharge at which the normal upper pool level could be maintained. Use of overflow sections to reduce the length of the gated spillway would tend to increase velocities in the lock approaches. The crest of overflow weirs or sections is generally 2 to 3 feet above the normal upper pool elevation.

8-6. Design for Navigation. Overflow sections are sometimes designed to provide for navigation over the structure during high water; this would permit the lowering of the top of the lock walls. In some cases, short navigable passes consisting of overflow sections are installed in nonoverflow embankments for the passage of emergency plant and equipment when the locks are out of operation because of high water. The adverse effects of frequent inundation of the locks because of the preparations required, the cleanup before the locks can be placed back in operation, and the difficulty in predicting river stages are factors to be considered in deciding the amount to lower the tops of the lock walls. The navigability of overflow sections depends on the length of the section, the head over the section, and the alignment of currents upstream and downstream. Studies have indicated that upbound tows can negotiate the overflow section with a head up to 0.8 foot or more, depending on the power of the boat and load. Tows with limited power might encounter some difficulty in negotiating heads greater than about 0.5 foot if the section is approached at a slow speed. Generally, tows maintaining sufficient momentum to move the lead barges across the weir would encounter little or no difficulty if power is adequate to navigate against some of the higher velocity currents encountered in the stream. With the overflow section positioned next to the gated spillway and flow confined on the landward side, an upbound tow could block a sizable portion of the flow over the weir, causing an increase in water level on the land side of the tow. If the overflow section is relatively narrow, the difference in water level on the side of the tow could be sufficient to move the tow toward the spillway, causing the tow to slam against the abutment pier. The same condition could occur with the tow moving across the weir at a sizable angle to the direction of flow.

Section III. Effect of Structures on Currents

8-7. Upper Lock Approach. Locks placed in the channel of a stream form an obstruction to a portion of the flow of that stream. The effects of these structures on currents depend principally on the configuration and alignment of the channel upstream and downstream therefrom and the amount of contraction and expansion in channel width produced by the obstruction.

The usual effect of the sudden channel contraction in the upper approach to the locks is an outdraft or crosscurrent that affects the movement of a tow at a time when its rudder power is reduced because of reduced speed with respect to river currents. The intensity of the crosscurrents is dependent on the total discharge affected by the structure and is a function of the velocity of currents approaching the structure, channel depth, and width of channel affected by the structure, and, in some cases, by flow along the adjacent overbank. Since no two reaches of a stream are identical, the intensity of the crosscurrents in the upper lock approach will vary according to the site selected and the orientation of the structures with respect to the alignment of the channel and currents.

8-8. Lower Lock Approach. Because of the sudden expansion in channel width downstream of the lock or locks, a tendency for an eddy to form in the lower lock approach will exist. The eddy produces currents moving landward at its downstream end, upstream currents along its landward side, and currents moving riverward at its upstream end. A tow moving toward the lock with little or no rudder power because of reduced speed and upstream currents is affected by these currents which are constantly varying in size and intensity. Currents in the lower approach can also be affected by lock emptying, powerhouse releases, uneven gate operation, flow from or toward the overbank, and flow from tributary streams. Unless locks are carefully designed, these effects could seriously affect the movement of tows in the lock approach. Since conditions vary at each site and cannot be fully resolved by analytical means, hydraulic model studies with model towboat and tow are usually required to assure safe and efficient passage through the lock or locks.

Section IV. Lock Auxiliary Walls

8-9. Guide Walls. Guide walls are used to assist tows in becoming aligned for entrance into the lock chamber without jamming of the lock gates when the gates are recessed in open position. Guide walls for single locks are usually on the land side and have all, or at least a sizable portion, of their length straight with their lock-side face in line with the inside face of the adjacent lock wall. Guide walls themselves provide tows little or no protection from the currents, but mooring lines can be attached to the wall to assist tows in overcoming the effects of adverse currents. When currents are not a factor such as in a canal or lake the guide wall is usually placed to provide the best protection from the prevailing winds. Short guide walls angled away from the approach channel are generally provided on the opposite wall to prevent tows from hitting the end of that wall.

a. Upper Guide Wall. Currents along the upper guide wall force downbound tows approaching the wall to move close to the wall; mooring lines are attached that are used for snubbing the tows into alignment. If the pilot misjudges the currents, the tow is in danger of either hitting the end of the wall or moving too far from the wall to attach mooring lines. Tows angling toward the guide wall to attach mooring lines are in danger of having their stern moved riverward, toward the spillway, because of the decrease in rudder control created by the necessity to reduce speed when approaching the wall. Usually, the wall can be approached safely by cautiously flanking toward the wall, attaching mooring lines, and snubbing the tow into alignment after mooring lines are attached. Upbound tows leaving the locks could also be affected by outdraft or crosscurrents that would tend to move the head of the tow riverward before the entire tow cleared the lock chamber. Because of the danger mentioned and delays that could be experienced in maneuvering for the approach, an upper guide wall without a guard wall or other protection is not recommended for single locks where currents of sizable magnitude can be expected along the wall and in the lock approach.

b. Lower Guide Wall. Upbound tows approaching the lower guide wall for entrance into the lock would encounter eddy currents which vary in size and intensity. Tows approaching the wall could encounter upstream currents along the wall and riverward currents at the upper end of the wall. Here again if the pilot misjudges the strength and position of the eddy at the head of the tow, he is in danger of hitting the wall or of passing too far from the wall to attach mooring lines. Experience indicates that eddy currents exceeding 1 foot per second are objectionable, and even currents of lower velocity could be a nuisance since they tend to move tows away from the wall. This tendency can be overcome by increasing power on the towboat or by attaching a mooring line to the wall. Conditions created by a lower guide wall are generally not as hazardous as conditions in the upper approach; nevertheless, they could cause considerable delays, depending on the intensity of the eddy and experience of the pilot. In some cases, the objectionable condition can be minimized or even eliminated by installing low structures along the river side of the approach channel.

8-10. Guard Walls. Guard walls provide tows with some protection from adverse currents and are usually on the spillway side of the lock. Guard walls might be used in addition to the regular guide wall or could be designed to serve as a guide wall also. Guard walls may be solid, ported, or spaced intermittently, depending on their purpose and their alignment relative to that of the lock and currents.

a. Upper Guard Wall. The upper guard wall can be an important factor in the safety of downbound tows and protection of the structures. The upper guard wall, when used as a guide wall, is generally as long as the clear portion of the lock chamber. Once the tow is behind the wall, it is safe from the effects of currents that would otherwise move the tow toward the spillway. With a solid upper guard wall, crosscurrents near the end of the wall would tend to move the head of downbound tows riverward and put them in danger of hitting the end of the wall. Also, there would be a tendency for an eddy to form between the wall and the adjacent bank, producing a riverward current near the upstream end of the wall and a landward current some distance downstream. Downbound tows must reduce speed as they approach the end of the wall, thus losing steerageway and the ability to overcome the effects of these currents. The danger involved depends on the intensity of the currents and the distance between the wall and adjacent bank. The landward currents near the downstream end of the eddy are usually not serious; however, they could slowly move the head of a stopped downbound tow away from the wall. The intensity of the crosscurrents depends on the amount of flow the guard wall tends to intercept. Upper guard walls are generally straight, especially when the lock is adjacent to the spillway. Flaring of the guard wall would increase the amount of flow the wall intercepts and could affect the distribution of flow through the spillway gatebays near the lock. Crosscurrents near the end of the guard wall can be eliminated or their effects minimized with properly designed ports in the wall. Design of ports in guard walls is discussed in a subsequent paragraph. Crosscurrents near the end of the wall could also affect upbound tows leaving the lock, moving their heads riverward before they had cleared the wall.

b. Lower Guard Wall. Lower guard walls provide tows protection from currents resulting from spillway discharge, uneven gate operation, powerhouse releases, and lock-emptying outlets located on the river side of the lock. Generally, an eddy will tend to form in the lower lock approach downstream of the end of the wall. The currents in the eddy move toward the adjacent bank at its lower end, then upstream along the bank, and riverward on its upstream end, just downstream of the end of the guard wall. The eddy will tend to move the head of an upbound tow riverward as it approaches the end of the wall. With a guard wall, this condition is not serious since the tow can approach the end of the wall some distance landward of the wall and the outdraft will assist the tow in moving toward the wall. When a tow is stopped with a portion of the tow extending beyond the wall, the currents would tend to move the stern riverward and could cause the head of the tow to move away from the wall. This movement could be resisted with some power on the towboat or mooring lines attached to the wall. The lower guard wall when used as a guide wall is usually the same length as that of the lock chamber; however, under some conditions it could be one half to two thirds that length depending on the alignment and intensity of currents.

Section V. Arrangement of Locks and Auxiliary Walls

8-11. Single Lock. Walls used to assist tows in approaching and entering the locks vary in type and arrangement. In their simplest form, single locks might include guide walls, guard walls, or a combination of both. Guide walls are usually on the land side of the lock (fig. 8-1a); guard walls are usually on the river side (fig. 8-1b). Some locks have an upper guard wall and a lower guide wall (fig. 8-1c). The upper gate pintles of most locks are along the axis of the dam so as to place the lock chamber in the lower pool, reducing pressure on the lock walls when lock is dewatered. When the guard wall is of sufficient length, it also serves as a guide wall for the lock.

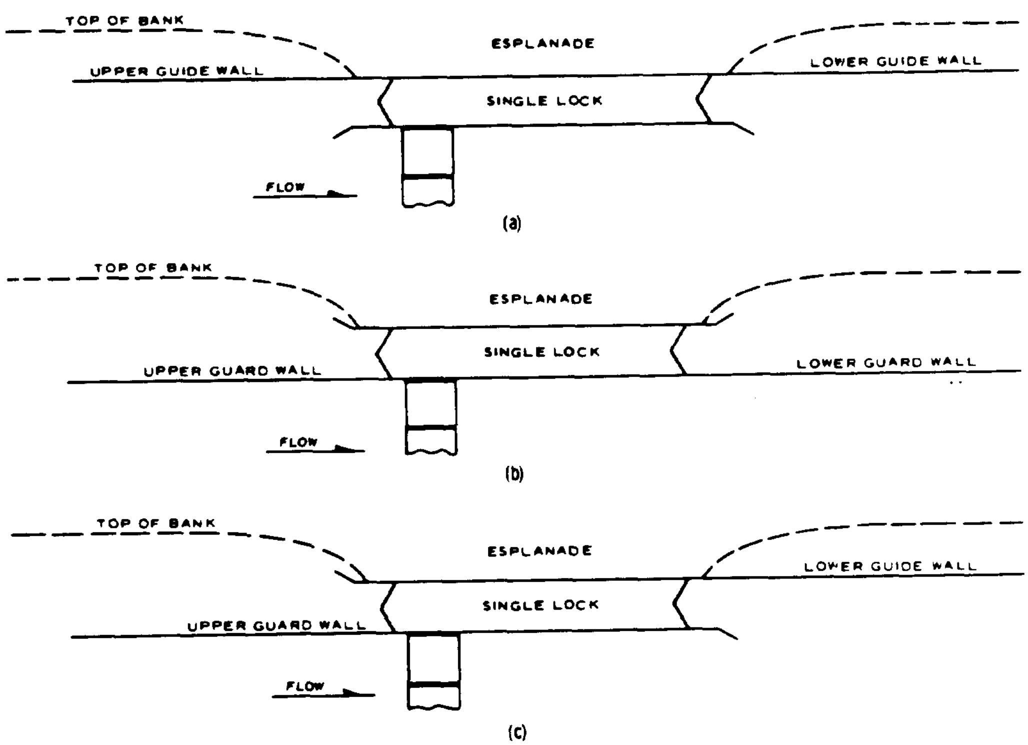


Figure 8-1. Arrangement for single lock

8-12. Adjacent Locks. With two adjacent locks, there is a common inter-mediate wall. The general practice has been to equip the river-side (main) lock with a ported upper guard wall and a solid lower guard wall. The land-side (auxiliary) lock usually has an upper guide wall (land side of the lock) ad a lower guide wall. When the land-side lock is shorter than the river-side lock, the land-side face of the intermediate wall extending beyond the end of the auxiliary lock could be used as the guide wall (fig. 8-2a). When the upper guard wall is ported, tows tend to be moved toward the guard wall because of flow through the ports, making it somewhat difficult for downbound tows to approach the guide wall for passage through the land-side lock. The difficulty is increased when the land-side lock is the same size as the river-side lock. Another problem confronted with this arrangement is that a tow cannot safely approach either lock when another tow is leaving or tied up along the guide or guard wall, resulting in delay for approaching or departing tows.

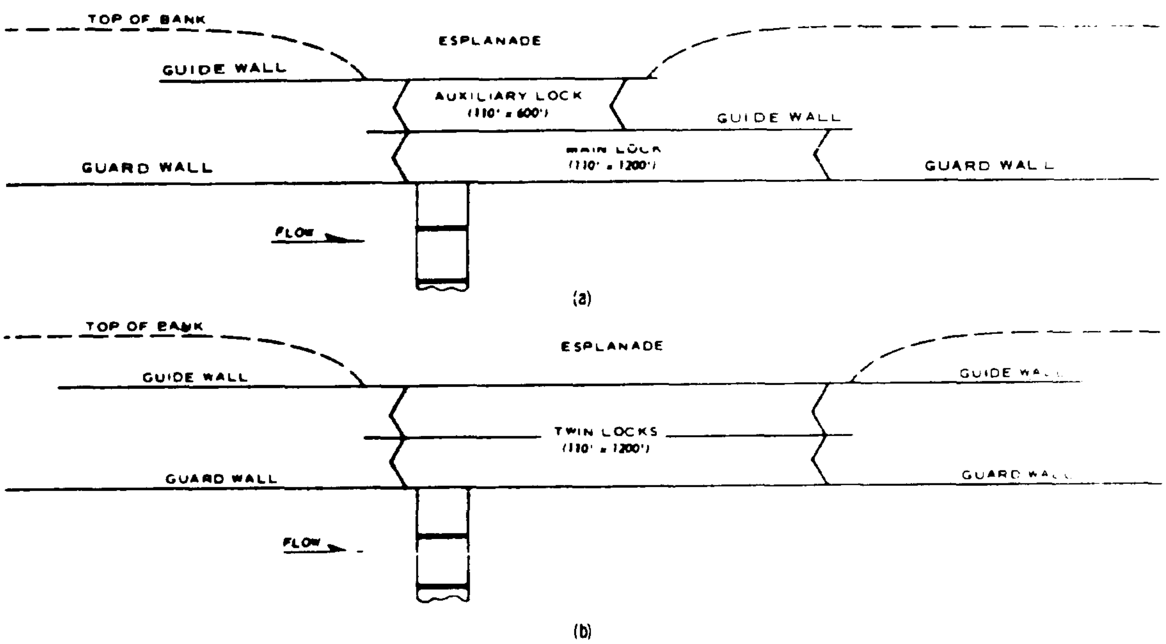
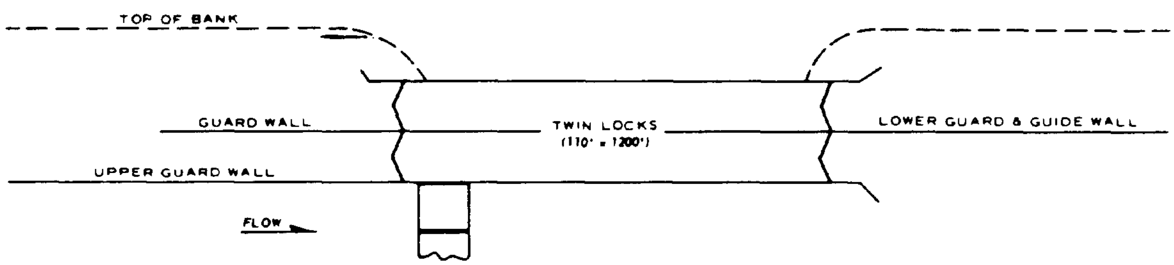


Figure 8-2. Arrangement with adjacent locks

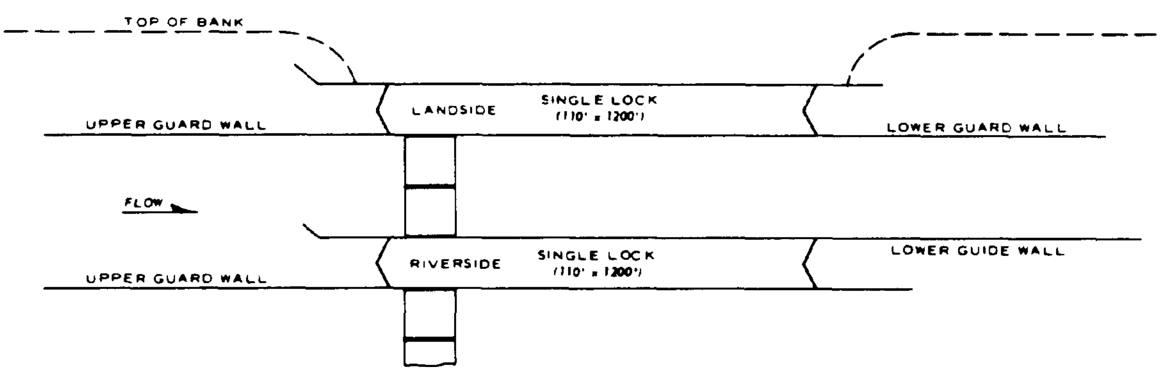
Section VI. New Arrangements of Locks and Auxiliary Walls

8-13. General. Based on the results of model studies, new concepts in lock arrangements have been developed to provide safer and more effi-cient movement of traffic through the locks. These concepts were developed for use with two parallel locks of the same size. The first concept involves the use of adjacent locks; the second involves the use of separate locks.

8-14. Upper Lock Walls with Adjacent Locks. The new concept is to provide an upper guard wall for both locks when the locks are adjacent (fig. 8-3a). Both guard walls would have to be ported. The land-side guard wall should be at least half the length of the usable portion of the lock chamber and the river-side guard wall should be of sufficient length to extend at least three fourths of the length of the usable portion of the lock chamber beyond the end of the guard wall for the land-side lock. These lengths are based on limited tests with specific projects and some variations might be desirable, depending on local conditions. The same arrangement could be used with adjacent locks of different sizes with the upper gate pintles of both locks along the axis of the dam. Since there would generally be little flow through the ports in the land-side lock guard wall, the tops of the ports should be a few feet higher than those in the river-side wall to develop



(a)



(b)

Figure 8-3. New concepts in lock arrangement currents that would assist tows in approaching the wall. As a result of this arrangement, a downbound tow could approach the river-side lock and be followed by a downbound tow approaching the land-side lock as soon as the tow using the river-side lock has landed along the guard wall. Also, a downbound tow using the land-side lock can approach the lock while an upbound tow is leaving the river-side lock; and a downbound tow could approach the river-side lock while an upbound tow is leaving the land-side lock, provided the head of the upbound tow does not extend beyond the end of the land-side guard wall.

8-15. Lower Lock Walls with Adjacent Locks. In the lower approach, the new arrangement provides for the extension of the intermediate wall to form a guide wall for both locks (fig. 8-3a). The land-side and river-side faces of the wall would have to be in line with the inside faces of the adjacent locks and constructed to withstand the impact of tows approaching the wall from either side. With this arrangement, tows entering or leaving one lock would not interfere with tows entering or leaving the other lock. For safe two-way traffic, the length of this wall should be the same as that of the tows using the locks. In addition to the advantage of two-way traffic, a long intermediate wall would cause a more gradual increase in channel width than with a long river-side guard wall, thereby reducing the shoaling tendency and, in turn, maintenance cost and interference with traffic during maintenance dredging. Shoaling, if any, would start in the approach to the river-side lock where it could be removed without interfering with traffic using the land-side lock. The only disadvantage attributed to this scheme is that upbound tows approaching the river-side lock would use more power since they would be moving farther out into the channel in higher velocity currents and would encounter some currents along the river side of the wall. However, this disadvantage is more than offset by the elimination of delays and power required to maintain position in the stream while waiting for other tows to clear the locks.

8-16. Separation of Locks. The second concept involves separation of the locks to provide two-way traffic in either or both directions (fig. 8-3b). The amount of separation required is presently a matter of opinion and could vary depending on local conditions. Navigation interests have indicated that a separation of about 270 feet was acceptable in the case of a replacement structure on the upper Mississippi River. Based on the movement and passing of tows through restricted reaches and bridge spans and on results of model studies, it appears that separations of about 200 feet or less might be adequate under most conditions. Separation of the locks would produce a greater obstruction to flow and result in an increase in crosscurrents in the lock approaches. To reduce the effects of the obstruction, spillway gates should be provided between the locks to pass some of the flow affected by the locks. This would reduce the crosscurrents produced by the total flow moving toward the spillway across the riverward lock approach; the size and intensity of the eddy that would be developed in the lower approach would also be reduced since the amount of channel expansion would be reduced. The hydraulics involved in the development of satisfactory navigation conditions with lock separation are more complex than for adjacent locks; design should not be finalized without benefit of a model study.

a. Upper Approach. In the upper approach to the locks a guard wall would be required on each lock. The guard wall would be on the river side of the land-side lock and could be on either side of the river-side lock depending on flow conditions and configuration of the channel upstream of the lock. The lengths of the upper guard walls should be at least three fourths the length of the usable lock, depending on the currents existing after completion of the project. The river-side lock upper guard wall generally needs to be longer than that of the land-side lock and, in most cases, at least as long as the lock chamber.

b. Lower Approach. In the lower approach the guide wall could be on either side of each lock. In most cases, it would be better to have the guide wall on the river side for the landward lock and on the land side for the riverward lock. This would provide greater separation of traffic approaching and leaving the lower lock approach. The length of the guide wall on the land-side lock should be at least half the length of the usable lock chamber and on the river-side lock at least two thirds of the length of the lock chamber.

8-17. Lock on Each Side of Channel. Lock separation could also be accomplished by placing locks on both sides of the channel with the gated spillway between the locks. This arrangement would be ideal for two-way traffic and would be preferred by navigation interests. In most streams it would be extremely difficult to develop currents in both lock approaches that would not be objectionable to navigation, particularly during higher flows. However, in an alluvial stream where the movement of sediment is involved, it would be impractical since the development of a channel of adequate depth on both sides of the river would require considerable maintenance dredging. Training structures designed to provide adequate depths would tend to affect navigation conditions in the lock approaches and could affect flow through the spillway. This arrangement could be practical in some straight reaches of channels carrying little or no sediment. The need for additional operating personnel would increase the cost of operation with this arrangement.

8-18. Locks in Canal. Locks located in a canal bypassing the dam in the main channel should be provided with guide walls to assist tows in becoming aligned for entrance into the lock. Since there are usually little or no currents in the canal, walls can be shorter than those required in the main channel, particularly with a single lock. When twin locks are located in the canal, extension of the intermediate lock wall can be used as guide walls in the upper and lower approach as shown in figure 8-4. This arrangement should be less costly than separate guide walls for each lock and could permit two-way traffic under most conditions because of the separation provided by the center wall.

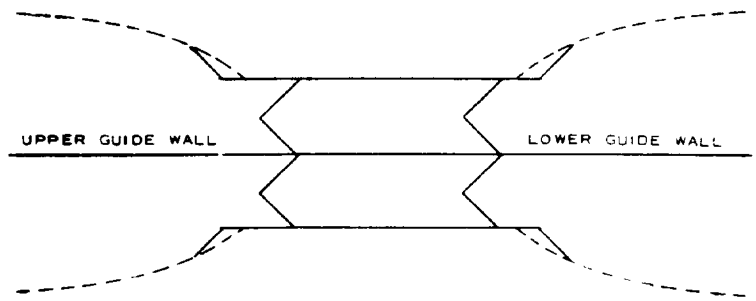


Figure 8-4. Twin locks with common guide walls

Section VII. Lock Size and Number

8-19. Lock Selection. The selection of the size and number of locks should be based on the requirements of the anticipated waterway traffic, with consideration of the characteristics of the waterway on which located. A thorough study of the equipment which will likely be using the lock and the size of barges and tow formations favored by the towing industry should be made before selection of lock sizes. The trend in barge construction has been toward larger units, especially for liquid cargos, varying from 35 to 48 feet in width and 195 to 300 feet in length. The type of bulk commodity that would be moved on the waterway would influence to some degree the size of barges and tow formations. The following are the standard lock sizes recommended by the Corps of Engineers:

Usable Lock Dimensions, Feet	
Width	Length
84	400
84	600
84	720
84	800

(Continued)

Usable Lock Dimensions, Feet	
Width	Length
84	1200
86	675*
110	600
110	800
110	1200

* Columbia and Snake River only.

Deviations from the above might be justified under special conditions and in the interest of safety and efficiency. On waterways where only small size crafts can be accommodated, smaller locks would be adequate. The use of more than one lock would depend on the volume of traffic expected and whether or not closure of the lock for repairs can be afforded.

Section VIII. Special Lock Features

8-20. Filling and Emptying Systems. Time required for tows to pass through a lock is affected by approach conditions, lock filling and emptying time, and to some extent the elevation of the lock floor and sills. **Under maximum head most locks are designed to permit filling and/or emptying in 6 to 12 minutes. The details of the various types** of filling systems that meet the requirements with least cost are covered in EM 1110-2-1604. The types generally recommended are:

Lock Lift, Feet	Filling System
0-10	Front end (sector gate or lock culvert)
10-40	Side ports
Over 40	Horizontal split bottom longitudinal

Sketches of these filling systems are shown in figures 8-5 through 8-7. The effects of lock filling and emptying on navigation conditions are discussed in another section of this manual.

8-21. Chamber Floor and Gate Sill. The lock floor elevation is established to allow rapid filling and emptying while maintaining reasonable

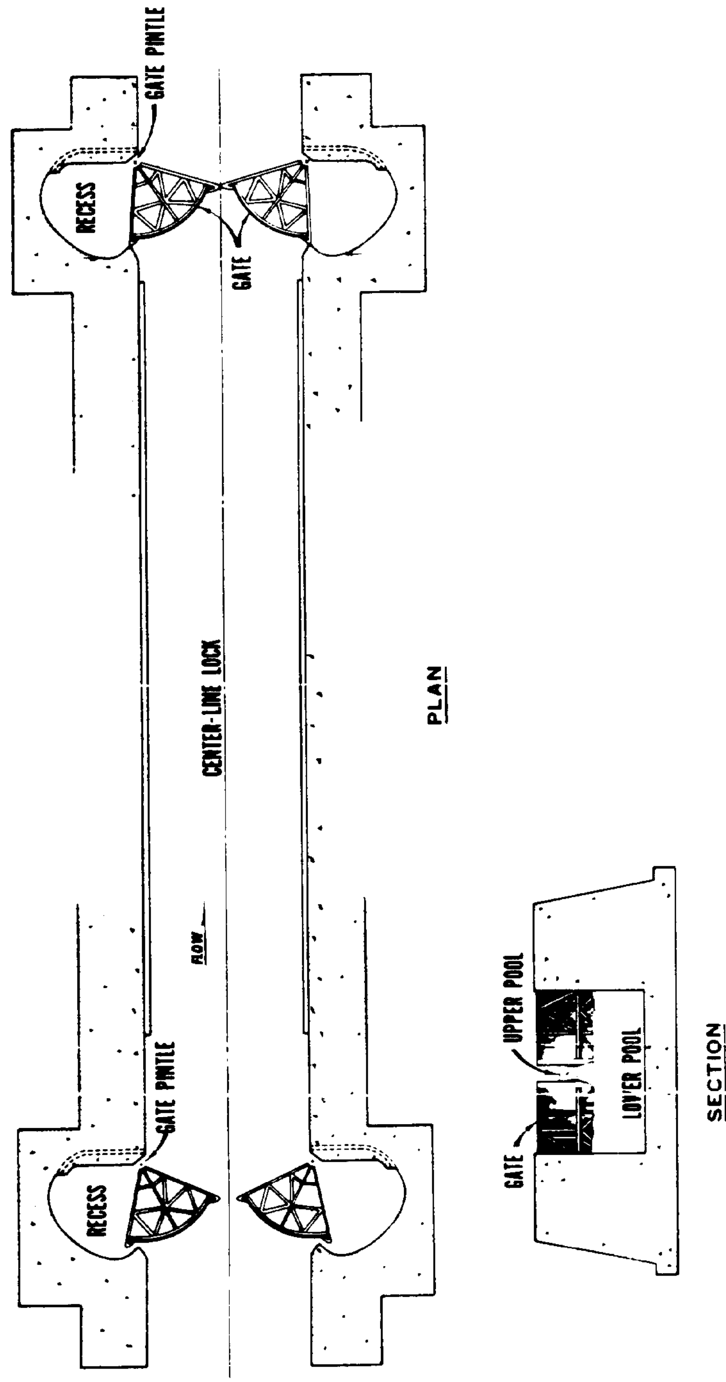


Figure 8-5. Sector gate

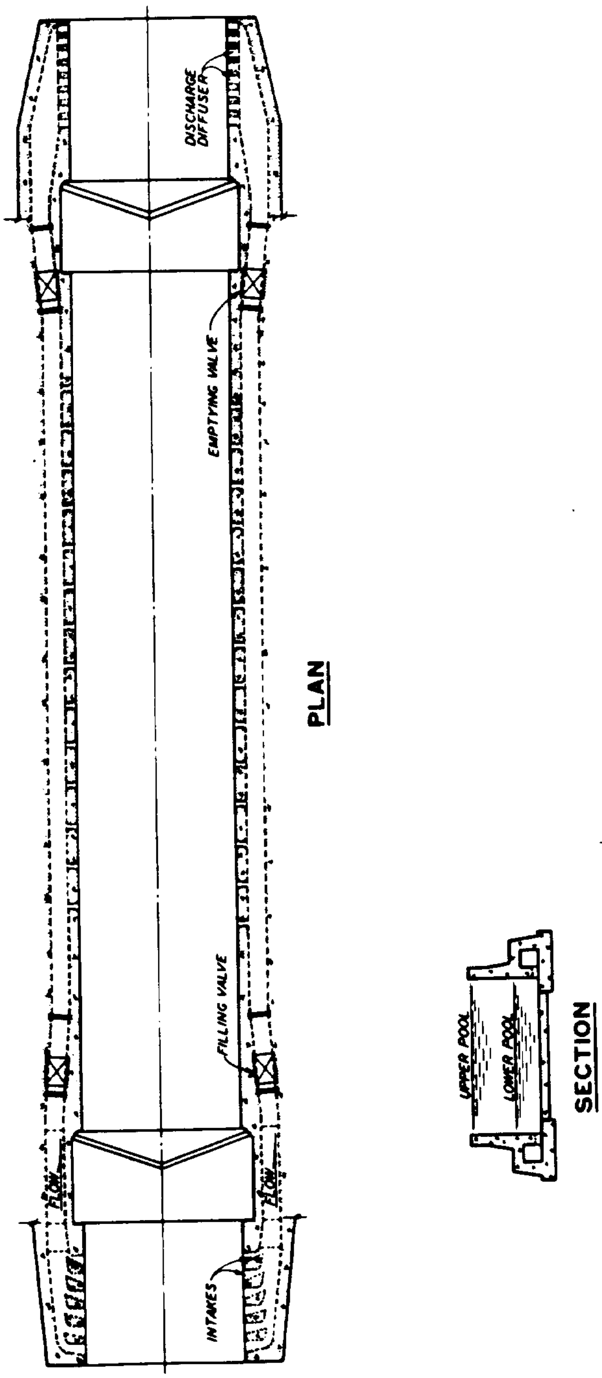


Figure 8-6. Sidewall port

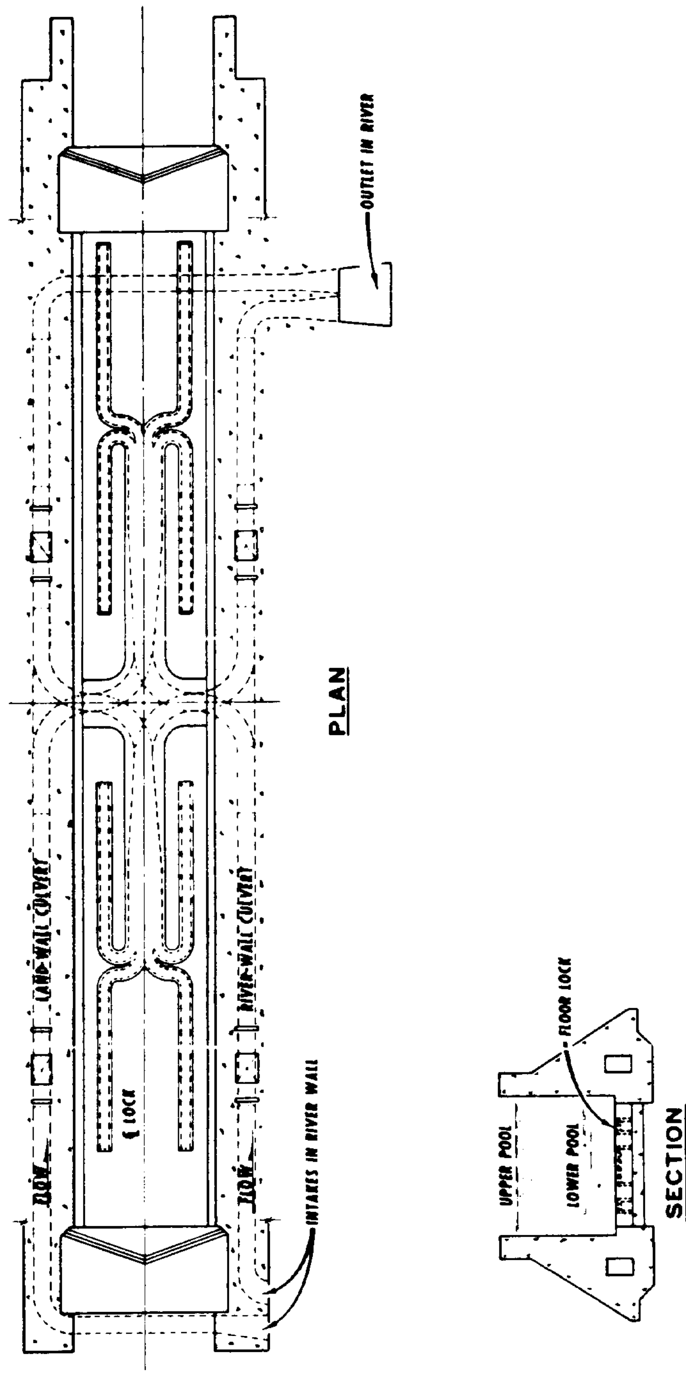


Figure 8-7. Longitudinal floor culvert

hauser loads. To meet this objective, an adequate space must be provided between the vessel bottom and floor so the filling water jets do not strike the vessel. When the lock floor is established the sill elevation can be determined. Detailed studies using model test results will define floor elevation more exactly. The gate sill should be as low as possible to allow a large water cross section for displaced water to exit the chamber (fig. 8-8). A 2- or 3-foot-high sill (above chamber floor) is often desirable to provide a space for gate seating and maintenance work and to keep sediment and debris out of the chamber. The minimum depth over the upper gate sill should be at least the same as the minimum depth over the lower gate sill. Comparison studies show increased cost for a higher gate is about equal to the savings in concrete for a low sill. Sector gated locks (front end filling system) usually do not have sills; the gate bottom is the same elevation as the chamber floor.

8-22. Lock Walls. The height of the lock walls should depend on the importance of the waterway and protection required for navigation, the characteristics of the waterway and type of dam selected, type of lock structure in connection with the foundation available, balance between initial and maintenance cost, need for uninterrupted traffic during high stages, and other conditions that might be peculiar to a given location. On important waterways where commercial traffic is not interrupted by currents, floating debris, ice, or other navigation hazards serious consideration should be given to providing lock walls of sufficient height to accommodate traffic during all but the most infrequent floods. If traffic cannot be accommodated during most of the year or is subjected to frequent interruptions, the full potential of the waterway would never

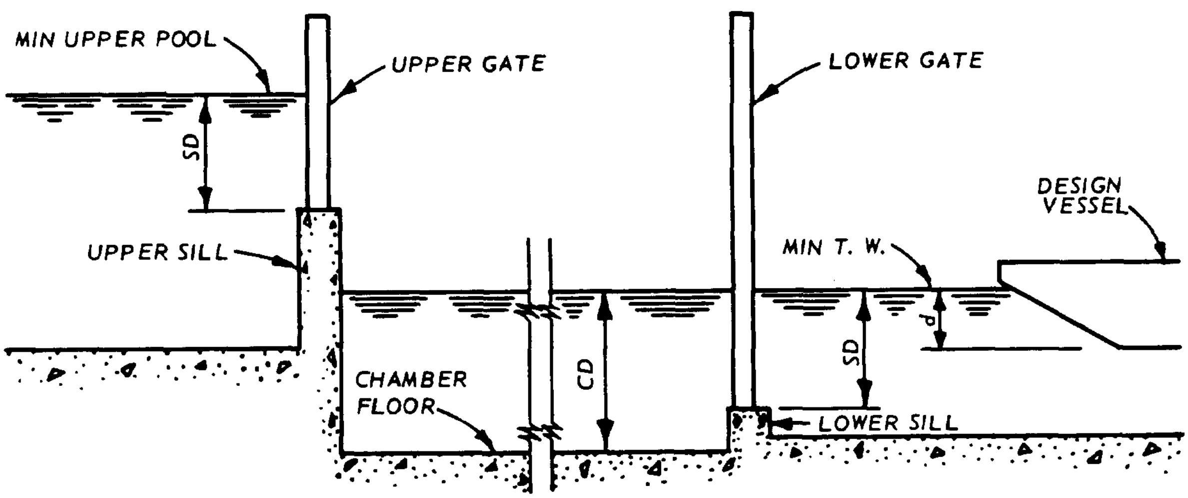


Figure 8-8. Lock longitudinal profile

be realized. Generally, the tops of the lock walls are set so that the longest period of traffic interruption would not exceed 10 to 15 days during the largest flood of record. In order to provide protection for tows, particularly those with empty barges, lock walls should be at least 2 to 3 feet above the maximum navigable stage depending on currents and wind that could affect navigation. In some cases, a considerable saving in initial construction cost can be realized with lower lock walls and a navigable overflow section in the dam with an operative system suitable for frequent submergence. However, frequent submergence can present many problems and increase operation and maintenance cost because of preparations required, cleanup and restoration, and difficulty of predicting changes in river stages.

8-23. Types of Construction. The resistance of concrete to impact, abrasion, and deterioration has caused this type of construction to be accepted as the most suitable for Corps projects. This type of structure permits the use of fast filling and emptying systems and should have a life expectancy in excess of 50 years. Sheet-pile locks have been constructed on the Ohio River (Locks 52 and 53) to alleviate congestion until permanent structures can be provided. These locks have a relatively low initial cost but generally have longer filling and emptying time, high maintenance cost, and a life expectancy of only 15 to 25 years.